

PROPERTIES OF THE SPOKES IN COAXIAL AND PARALLEL - PLATE PLASMA ACCELERATORS

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ABSTRACT

Image converter photographs¹ have shown that the "spokes" produced in the plasma coaxial accelerator at 2 mm hydrogen pressure are produced in pairs. Magnetic probe measurements indicate that the spokes have roughly the magnetic structure of a quasi-force-free configuration. Although the structures are too small in diameter (1mm) to make ion-density-flow probe measurements of their profiles, there are compelling reasons to predict that these structures have mass flow patterns which are roughly parallel to the quasi-force-free magnetic structure. Schlieren and spectroscopic techniques for measuring ion density profiles of the vortices will be described. Spectroscopic techniques for measuring rotational velocity profiles will also be described. Theoretical attempts to understand these structures as minimum energy configurations will be set forth.

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Two types of filamentary plasma-magnetic field structures^{2,3,4} which concentrate the plasma density the rotational plasma flow density, the amperian currents, and the perturbation magnetic fields have now been observed by image-converter photography to be produced in pairs.¹ These filamentary plasma structures are judged to be relatively stable since they observed not to exhibit kink or sausage instability, to exhibit only a moderate amount of flute instability, and since they spontaneously arise in a fraction of a microsecond and endure for many microseconds. These structures are called vortices because of their rotational nature. Both of these types of vortices are created in a background magnetic field. One type of structure has its filamentary axis lined up parallel to the background magnetic field (\parallel -to- B_0 vortex) and may be regarded as the result of a large amplitude, non-linear ion acoustic wave or

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collisionless shock wave. The other type of structure has its filamentary axis lined up perpendicular to the background magnetic field (\perp -to- B_0 vortex) and may be regarded as the result of a large-amplitude, non-linear Alfvén wave. This \perp -to- B_0 vortex has been produced and studied extensively in the conical θ pinch experiments^{3,4,5} where the filament becomes a torus and where the measurements of perturbation magnetic fields and ion-density flow patterns show that the field- and flow-patterns have the shape roughly of a force-free configuration.

The spokes which have been observed, sometimes as an annoyance, for years in plasma coaxial accelerators can now be identified as \perp -to- B_0 plasma vortices. With hydrogen at 2mm pressure these vortices can be produced in pairs in a spectacular way if the center conductor of the coaxial accelerator is not circular but, for example hexagonal, as in figure 1. The spokes emanate, not from the corners, as one would naively expect, but from the flat sides of the hexagonal center conductor. Magnetic probe measurements show that there are perturbation magnetic fields directed along the filamentary axis of these vortices photographed in figure 1. The formation of these vortices in pairs^{MAY} can be understood in a phenomenological way by means of figure 2. Here the magnetic field is weaker on the flat and stronger at the corners of the hexagonal center conductor. The magnetic field of the coaxial accelerator which is ordinarily purely azimuthal, "gives" where it is weakest to form a kind of pocket at the flat of the coax. The mass of gas rushing into the current sheath in the current sheath frame of reference starts to circulate in two vortices in this pocket and at the same time flows toward the outer conductor because of the "bullet shape" of the current sheath. The resulting plasma flow density in each vortex of the pair is helical, one being right-handed, the other left-handed. The background magnetic field lines which are ordinarily azimuthal are apparently "spun" into helical filaments by these plasma mass flows.

The striations which have been seen in the θ pinches by Bodin⁶ and Kvartskhava⁷ and Z pinches by Kvartskhava⁷ are very likely examples of \perp -to- B_0 vortices. A pre-print received from Kolesnikov and the Filippovas⁸ shows similar striations being produced in pairs.

It has thus far proved impractical to try to delineate with ion flow probes the flow patterns and density profiles of these \perp -to- B_0 vortices in the coaxial accelerator because the dimensions of the vortices are so small (~ 1 mm in diameter). Instrumentation has now been constructed to measure the density profiles of these vortices with Schlieren photography. The Schlieren techniques will first be employed with the

parallel plate accelerator where the "windows" can easily look at the vortices. It is also planned to use Stark broadening to measure density profiles of the vortices and doppler shift on impurity lines for measuring rotational profiles.

A "Plasma camera" technique for measuring ion densities has been effectively employed for studying the properties of \parallel -to- B_0 plasma vortices produced by firing a two-wire button gun in a magnetic field (see fig.3). ^{Efforts} ~~Effects~~ are underway to adapt this technique for measuring the \perp -to- B_0 vortices.

Initial theoretical attempts following Woltjer¹⁰ to describe plasma vortices with MHD equations where the energy is made an extremum subject to certain constraint integrals lead to magnetic field and flow configurations which are roughly of a general force-free type. However, this approach can be used only to demonstrate equilibrium (energy extremum) not stability (energy minimum), and it depends upon assumptions about boundary conditions at infinity which are not realistic. An approach which uses orbit equations for a two-species of particles appears much more promising.

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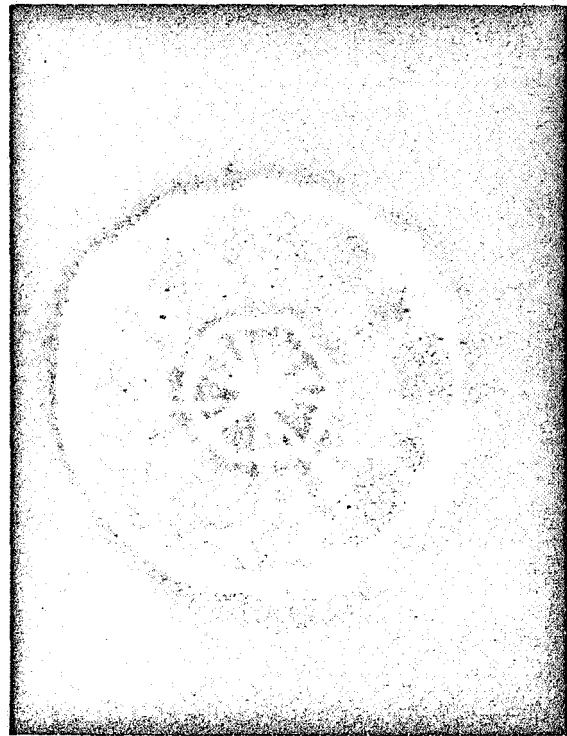
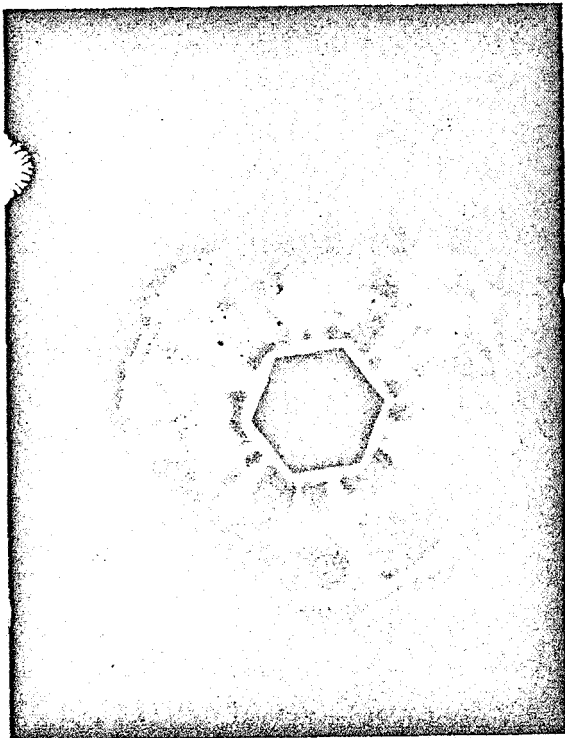


FIG. 1. Image converter photographs, end on, of a plasma coaxial accelerator, o.d. 5 cm, where the center conductor which is 4 cm long, is hexagonal. The accelerator is operated with H_2 gas at a static pressure of 2 mm. The formation of pairs of perpendicular-to- B_0 vortices at each flat side of the hex is striking. The peak current in the accelerator is 150kA, the half-cycle is 1.5 μ sec. The left photograph is taken 0.8 μ sec after the beginning of the current half-cycle; right photograph taken at about 1.0 μ sec when the vortices have coalesced in the pinch at the end of the center conductor. The authors suggest that the coming together of these force-free type filaments at the end of the center conductor is analogous to the process which produces solar flares⁹ in the solar atmosphere.

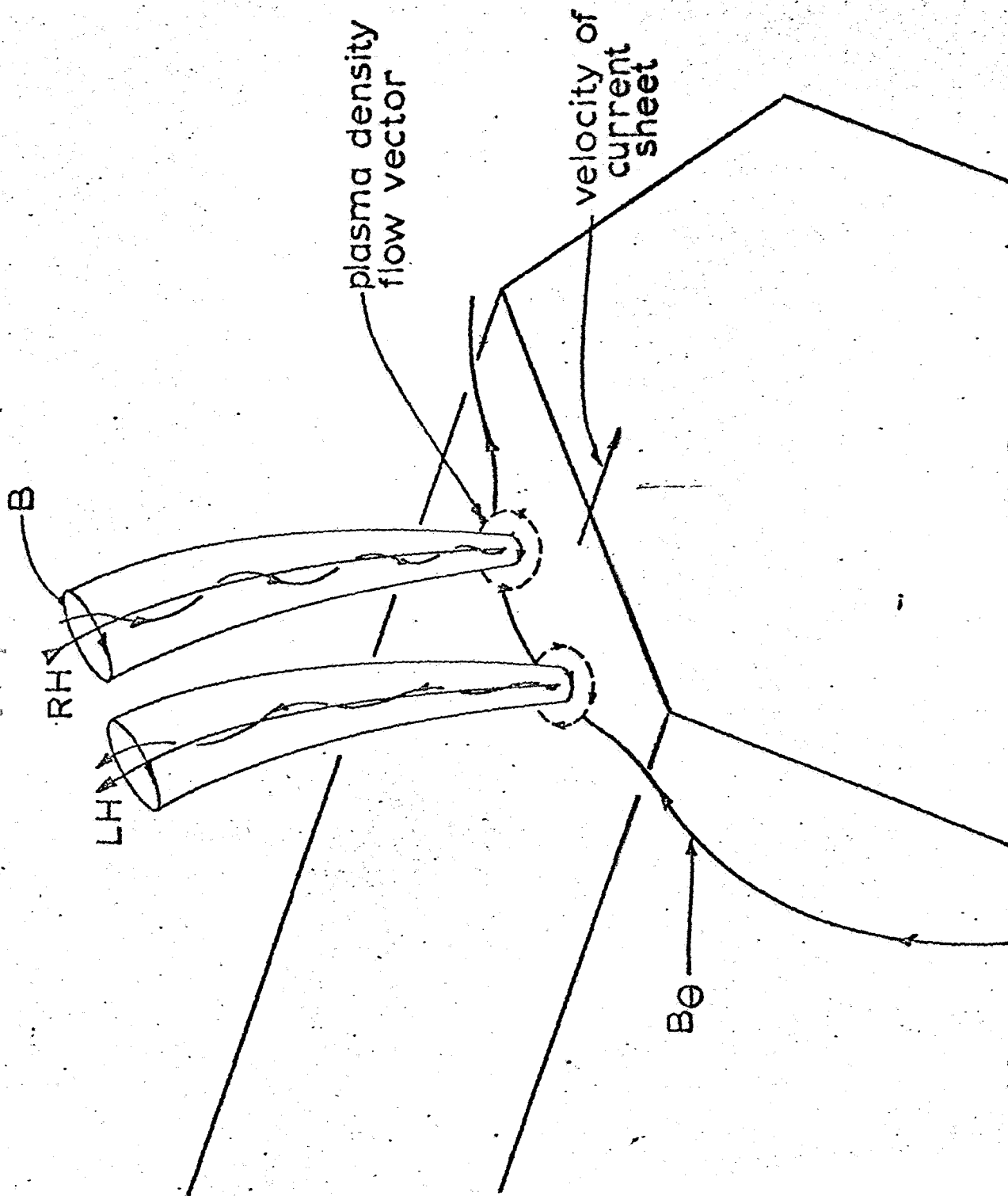


FIG. 2

Diagram showing how perpendicular-to- B_0 vortices may be expected to develop in pairs in the plasma coaxial accelerator with a hexagonal center conductor. The general geometry is somewhat similar to that expected from resistive instabilities in the tearing mode.

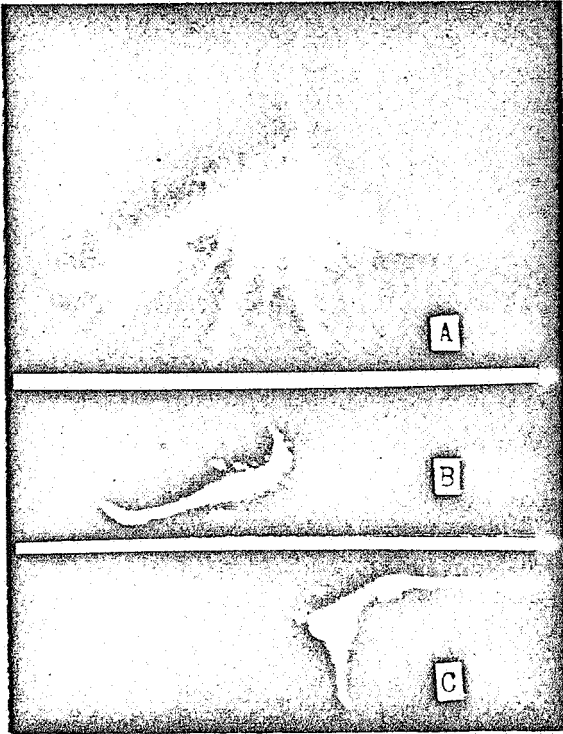


Fig. 3. Illustrates the technique of recording plasma density with a "Plasma camera".^{11,12} The camera consists of two accelerating grids and a plastic scintillator (NE102) all aligned perpendicular to the magnetic field. A short (0.2 μ sec) pulse is applied to the grids so as to drive electrons from the plasma into the scintillator. The pattern of illumination is thus representative of the plasma density near the front grid at the time of the pulse. In the following photographs peak plasma density is estimated to be 10^{13} /cc. PHOTO A. A copper two-wire button gun with upper electrode negative fires anti-parallel to the magnetic field toward the plasma camera which is 4" away. The tiny gun is in the center of the photograph, the field is 400 Gauss and goes into the plane of the photograph. Note complicated striations which develop at these low magnetic fields.

PHOTO B. Same as above with $B=1600$ Gauss. Note the tendency for the plasma to be driven in the $j \times B$ direction.

PHOTO C. Same as Photo B. but with gun polarity (i.e. j) reversed. Plasma is driven in the opposite direction.